Assessment of an RFID System for Animal Tracking

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Abstract

We evaluated the Multispectral Solutions, Inc. RFID system in several experiments to assess its utility in tracking animals as they move around their habitat. The system consists of tags which transmit a signal and receivers which use this signal to determine the location of the tag. Our results indicate that this system, as it currently exists, does not provide sufficient accuracy or precision to be able to track animals in their noisy and cluttered environment.

1. The Multispectral Solutions, Inc. RFID System

The Multispectral Solutions, Inc. System is a commercial-off-the-shelf active RFID system. The system consists of tags (transmitters) and receivers. A minimum of four receivers are required, although extras can be used for redundancy and accuracy improvement. The receivers should be placed around the edge of a "working volume" which contains the objects to be tracked. The receivers are daisy chained via CAT5 cable (for power and readings), with the chain ending in a "black box" hub. This hub connects to a computer and simply outputs coordinate information about each of the tags that are being sensed.

In order for the system to generate the locations of tags, the receivers must all be precisely calibrated. The system requires knowing their exact location (relative to one another). We defined one receiver as (0,0,0) and located the rest relative to that one. Further, one tag (transmitter) must be placed precisely and in plain view of all receivers. This tag is used solely to synchronize the receivers with one another temporally.

The system works as follows. The tags emit very short duration pulses which are uniquely coded. When the receivers detect a pulse, they send the exact timestamp information down the chain to the hub. The hub then uses this information to determine the location of the tag which emitted the pulse by using time of flight information. Since the receivers are not synchronized with the tags, the system cannot triangulate based on the time of flight from the tag to each receiver. However, since the receivers are all synchronized with each other, the relative time of flight can be determined. For example, if Receiver 1 and Receiver 3 both detect the pulse at the exact same time, then the tag in question is the exact same distance from Receiver 1 as it is from Receiver 3. Using this logic, four receivers are needed to pinpoint a tag's location in 3-D space. If only three receivers detect a tag, then a hypersurface can be found which contains the its location. If only two receivers detect a tag, then a paraboloid on which the tag sits can be found.

Because of the method in which this system performs localization, the positioning of the receivers is very important. If only 2D localization is desired, then placing the receivers all in the plane which the tags will be functioning in will result in the highest accuracy. However, with this configuration, any movements of a tag out of this plane will result in lousy accuracy. Therefore, for 3D localization, it is required that all receivers not be placed in a plane. It is also desirable for the receivers to be spread out, and as far from the "work volume" as possible. For example, if the tags are to be localized within a cubic volume, four receivers should be placed along the perimeter in the corners, with adjacent corners at different heights (two at the top of the volume and two at the bottom). A fifth receiver in this scenario is recommended to be placed at the top of the cube in the center, pointed downward.

2. Limitations

While this system boasts several useful features, it also suffers from some severe limitations for our application:

- **Accuracy:** The system returns a tag's location to within approximately 0.5m of its actual location. While averaging over time will result in a very good estimate of a static tag's location, this may not be sufficient to determine when two animals are within 10cm of each other.
- **Rate:** The system currently provides location information up to four times per second. In practice, tags often provide only one complete location per second (or less), this update rate may not be sufficient to create a track of an animal moving at moderate to high speeds.
- **Occlusions:** The system quickly breaks down in the presence of many types of occlusions. While objects such as plastic and ceramic have little effect on the system's accuracy, other objects, such as metal and animals (both the tag wearer and other animals) very easily completely obscure the tag from a receiver. In essence, complete line of sight (with regard to

metal and animal objects) is needed from the tag to all receivers in order to get a complete reading. Even with line of sight available, nearby objects are likely to cause a dramatic reduction in accuracy.

Taking these limitations together, it is clear that this system, as it currently stands, will not suffice for tracking animals in their habitat with the desired precision.

3. Methodology

All experiments were conducted using four receivers and a series of transmitter tags in a large, open area. The receivers were placed in the corners of a rectangular area approximately 20 meters by 10 meters. Their heights off the ground were varied, from about 2 meters to more than 10 meters. Our experiments consisted of three different types:

- **Static Testing:** These tests were used to determine the accuracy and precision of the system under ideal static, non-occluded conditions.
- **Dynamic Testing:** These experiments were used to test the feasibility of using the system to create a trace of movement over time.
- **Occlusion Testing:** This series of experiments was used to determine what materials have an effect on the accuracy of the system. The first experiments simply involved covering tags with different materials to see their effects. The further experiments consisted of placing tags on (and in) a turkey to determine how proximity to an object roughly the size and density of a small animal.

Figure 1. Setup for Experiment 1

These experiments were conducted using a series of nine tags. The tags were attached to wooden beams at one meter intervals, and arranged into a 3x3 grid.

4. Results

Figure 1 shows the setup of the 3x3 RFID grid which was hung vertically for experiment one. This static experiment tested the ability of the system to localize tags in three dimensional space. The grid was aligned parallel to

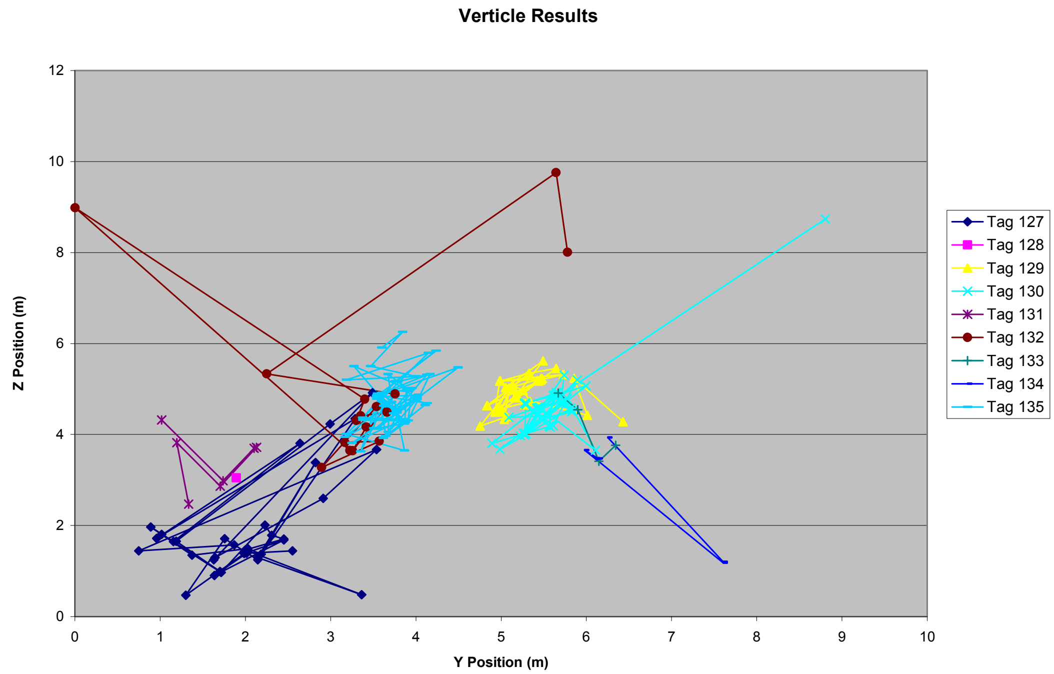

Figure 2: Three Dimensional Testing. Grid center is at (4,4).

the X axis so that all RFID tags would have the same X coordinate. Figure 2 displays the results if this experiment. As can be seen, the accuracy of the system in the Z-dimension is very poor. Part of this accuracy problem may be attributed to the wood that the tags are attached to. Later experiments show that wood does affect the ability of the receivers to detect the tags.

Figure 3: Dynamic Testing

The second experiment was designed to determine the accuracy of the system to track dynamic (moving) tags. The 3x3 RFID grid was attached to a rolling stool, and pulled slowly along a straight line. The person pulled the grid by a rope, in order to maintain distance from the tags so as to not occlude them from the receivers, as shown in Figure 3. By looking at the results (Figure 4), it is clear that the tags were moved generally along the X-axis, but the recorded points jump around significantly.

In order to determine which materials have an affect on the accuracy of the system (and how much that affect is), occlusion testing was performed. The 3x3 RFID grid was placed at a known location, and each individual tag was occluded by one of a number of objects. Two tags were left non-occluded as a control group. Figure 5 shows the setup, while the output from the system is shown in Figure 6. Some materials had little effect on the system, such as hard plastic,

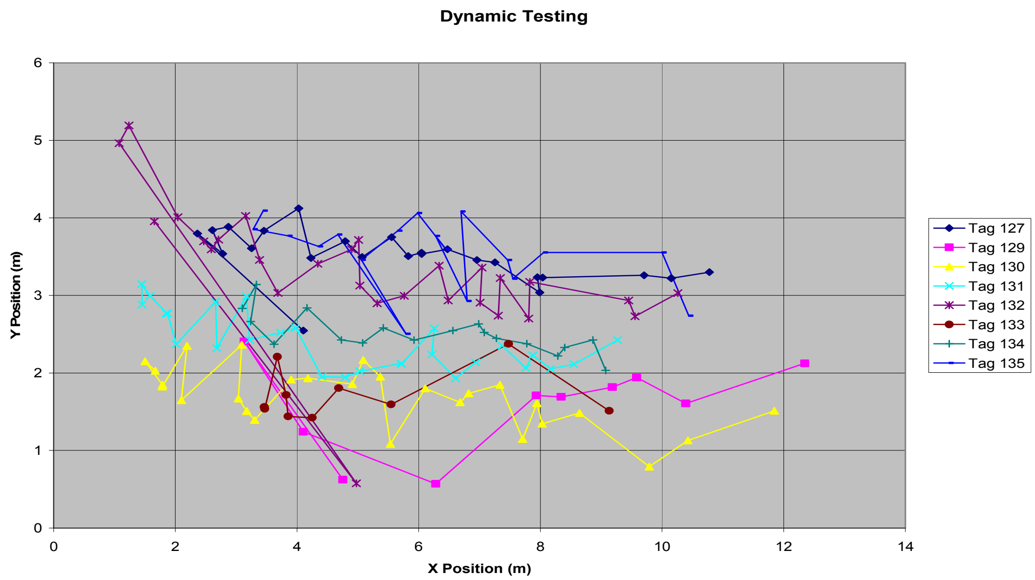

Figure 4: Dynamic Testing Plot. Grid should move along Y = 3m.

Figure 5: Occlusion Testing

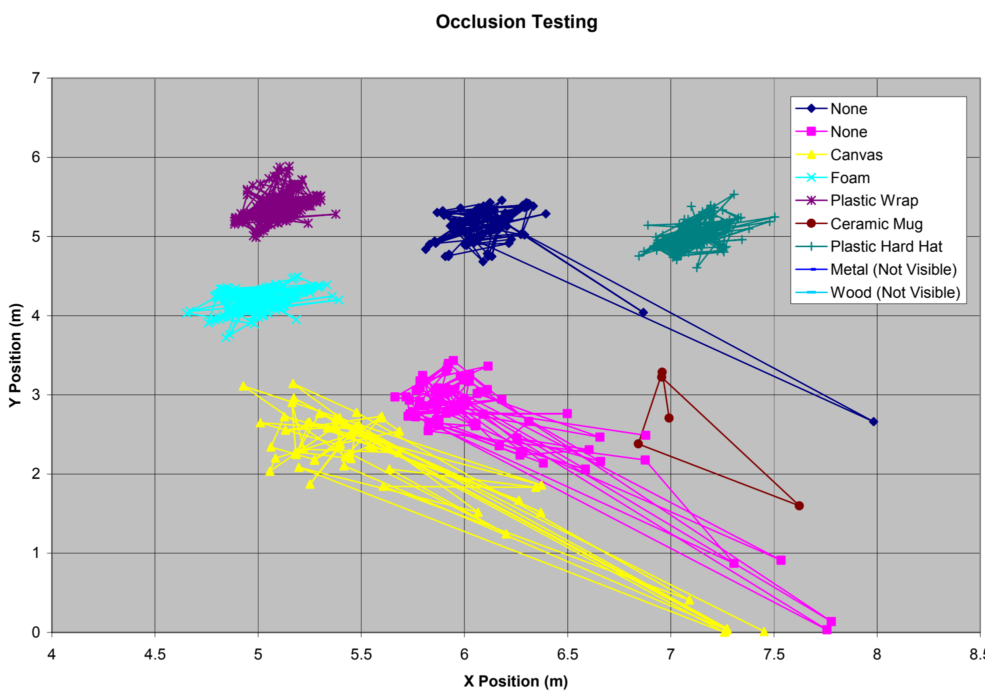

Figure 6: Occlusion Testing Plot. Grid center is at (4,4).

foam, and plastic wrap. Others had more of an affect. Metal and wood (surrounded by thick blocks) completely blocked the tag from the receivers, while ceramic affected accuracy and number of points recorded. Finally, note that proximity to the metal may be responsible for the “shifting” effect of the canvas and one of the non-occluded tags.

Figure 7: Staircase Occlusion Testing

The first occlusion experiment shows what materials have an affect on the system, but they don’t necessarily represent how the system would behave in a more realistic environment. To simulate such a situation, a metal staircase was placed over and around the tags (as shown in Figure 7). This could represent animals on, under, and near an open metal structure, of the sort that can be found in their environment. Figure 8 shows the data gathered by the system with the tags in this configuration. One of the tags was completely obscured (134), while a second was mostly obscured (135). Several others suffered varying degrees of decreased accuracy, depending on proximity to the metal, and whether or not it blocked the line of sight from the tag to one or more receivers.

The final set of experiments involved attaching two tags to the surface of a turkey, and embedding one under its skin. Virtually no data points were recorded from these experiments due to the mass of the turkey blocking the tags from at least two of the receivers. A few points were able to be gathered from the embedded tag, if the turkey was aligned precisely, which does demonstrate that the skin itself had little effect on the system. Figure 9 shows the turkey with the mounted and embedded tags. Finally, a tag resting near the turkey was completely occluded until the turkey was moved at least one meter away, showing that even small objects blocking the line of sight can be very detrimental.

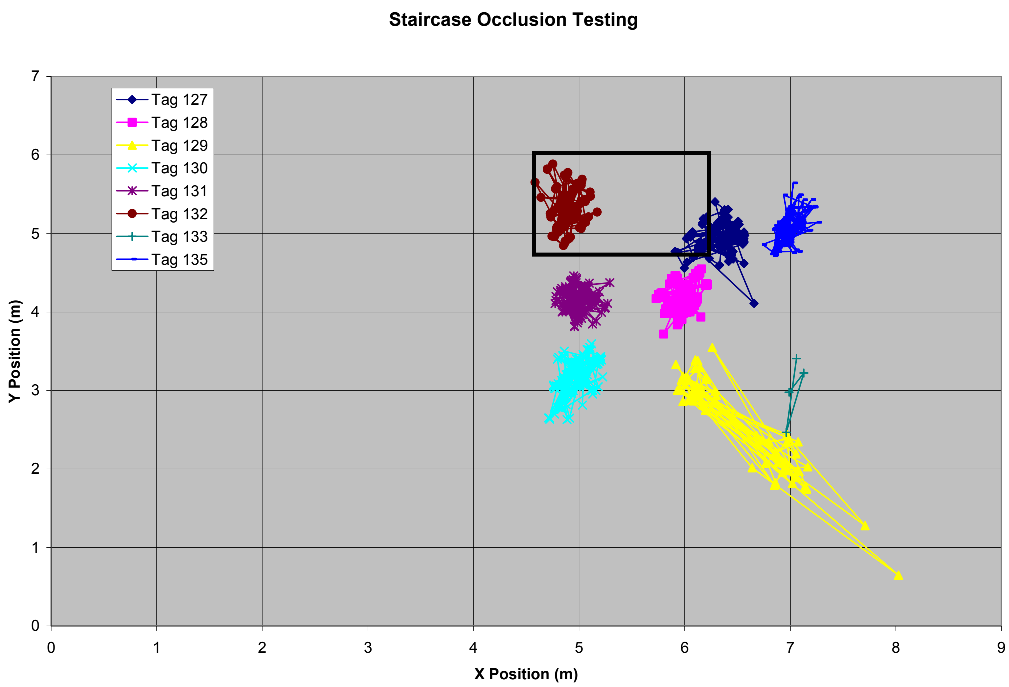

Figure 8: Staircase Occlusion Testing Plot. Grid center is at (6, 4). Black line indicates approximate staircase location.

Figure 9: The embedded and attached tags are circled in black.

Table 1 displays quantitatively the accuracy and precision of two tags from the second occlusion experiment. Tag 131, which was not blocked by the staircase, was far more accurate and precise than tag 129, which was partially blocked.

Table 1: Accuracy and Precision Example

Tag Id	Accuracy	Precision
131	0.14615 Meters	0.20165 Meters
129	0.70413 Meters	0.70413 Meters

5. Application of these Results

Our results suggest that this system, in its off-the-shelf state, cannot provide reliable localization of individuals in a large group of animals moving about their habitat.

There are several reasons for this assessment. Even in static environments, while the system has good accuracy over time, the precision (average distance between each estimate and ground truth) is quite low. Couple this with the frequency of only up to 4Hz, and the system cannot create a clear picture of a moving animal's path. To further complicate things, any line of sight occlusions (involving metal or other animals) between a tag and any of the receivers results in the occluded receiver not even detecting the tag. Finally, an animal wearing a tag as part of either a collar or backpack will defeat the system itself, virtually guaranteeing occlusions between the tag and one or more receivers.

Several suggestions on ways that the system may be "tailored" to fit this application include:

- **Double tagging:** If the system were able to treat two tags as one, then putting one on each side of an animal's neck would help increase the likelihood of enough receivers seeing the combined "single tag". Since the tags are so close together.
- **Higher Frequency:** If the system could work at a much higher frequency, then averaging of many points over a short period of time could be used to improve accuracy.
- **Additional Receivers**: Including additional receivers decreases the affects of occlusions by helping ensure that at least four receivers can detect a tag at all times.
- **Post Processing:** It is possible that post processing, combined with one or more of the above, can be used to smooth and average the data to generate a more useable track. This would require advanced calculations, taking advantage of the partial information returned when fewer than four receivers detect a tag.

It is our recommendation that the last two suggestions (those that we have control over) are not sufficient to allow this system to succeed for our application. However, it may be possible to generate passable results by combining all four suggestions, or others that have not been included in this report.

6. Acknowledgements

Thanks to Adam Jacoff and Brian Weiss for sharing both their knowledge and equipment.